Monitoring for the CALFED Bay-Delta Program ERP

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Introduction

Adaptive management for the CALFED Bay-Delta Program's Ecosystem Restoration Program (ERP), like any adaptive management approach, can be described as resource management that is informed by monitoring and research. The CALFED Bay-Delta Program agencies believe that with continuous feedback and revision, environmental management can become increasingly effective, efficient, and accountable. Ideally, management and data collection are designed in concert to maximize information gain, evaluate management in light of new information, and revise management direction in response to new information. Many believe, however, that the linkages between environmental management and data collection can be stronger both in the Bay-Delta system and on managed lands beyond the program area. More management actions and restoration activities need to be subject to monitoring, and monitoring efforts need to produce more useful information. The ERP is hoping to address both these opportunities in this solicitation for proposals.

An adaptive management approach was chosen by the ERP to address the high levels of uncertainty that accompany management of environmental resources in the Bay-Delta system, in the Sacramento and San Joaquin River main stems, and in their many tributaries. The ERP's approach to adaptive management recognizes that a range of management options for addressing environmental challenges typically exist, and that there are alternative ideas or hypotheses about how environmental systems function, that management actions can be designed to better understand environmental systems, and that monitoring programs can be used to assess the state of environmental systems and their responses to management.

The ERP's ability to draw reliable information from monitoring assumes that monitoring efforts carried out under the auspices of the program are reliable. Although most ecologists and resource managers have at least some idea of what monitoring is and what can be accomplished, the importance of improving monitoring data to inform management efforts highlights the need for a more rigorous and standardized paradigm. This paper offers some guidance, but addresses only a small portion of the issues that confront those who will design and implement monitoring plans and interpret their results. Accordingly, at the end of this discussion, we provide a short list of resources that contain further information directly pertinent to the development of monitoring programs.

Monitoring is not watching things happen. Monitoring is not counting. Monitoring is not measuring in the absence of a clear management context. But observing, counting, and measuring all play roles in monitoring programs. Monitoring is explicitly intended to provide information that can help us explain phenomena that concern us. A frequently cited definition of monitoring in environmental management is "measurement of environmental characteristics over an extended period of time to determine status and ends in some aspect of environmental quality." That deceptively simple definition can serve the ERP well. However, embedded in that definition are challenges that vex most experienced researchers and practitioners – which characteristics should be measured, using what measures, where, and for how long?

Most participants in monitoring recognize distinct applications of their efforts. Implementation (or compliance) monitoring, for example, is designed to track or verify the implementation of a management plan, compliance with a regulation, or performance on a commitment to restore or enhance a resource. Effectiveness monitoring, by contrast, evaluates status and trends of a system and its components that result from management actions in an effort to determine whether the action has achieved the desired target or outcome. In some cases validation monitoring is used in attempts to test assumptions about the cause and effect relationships that exist between management actions and targeted resources. And some restoration programs recognize trends monitoring as a distinct monitoring activity, where the status and trends of ecosystem elements are tracked to determine whether circumstances are returning to desired conditions. These categories are not mutually exclusive.

Effectiveness monitoring, a key focus of this solicitation, is the prime focus of the discussion below. Within the context of effectiveness monitoring, another distinction is important to recognize. Retrospective monitoring (sometimes referred to as effects-oriented monitoring) attempts to identify effects of management on ecosystems by monitoring changes in the status of an attribute, such as the population size of a sensitive species or the composition of a vegetation community. Retrospective monitoring strives to detect environmental changes after they have occurred, and attempts to attribute causation when an effect is found. In contrast, prospective or predictive monitoring (also referred to as stressor-oriented monitoring) attempts to detect factors that cause responses by elements of an ecosystem before undesirable effects occur or before those effects become serious.

Both retrospective and prospective monitoring have their merits. They can be complementary in a diversified monitoring program that assesses the effects of multiple management actions in a complicated field setting. But retrospective and prospective monitoring activities are not equally appropriate or useful in every assessment effort. When risks or costs of a failed management action are relatively low, the probability of detecting changes in the system are high or the lag time between cause and effect is short, retrospective monitoring may prove effective and less expensive than alternative options. When risks and costs are high, the ability to detect changes is comparatively low, and the lags in system response are relatively long, however, prospective monitoring is required. With substantial numbers of at-risk species in its purview, the CALFED Bay-Delta Program ERP must respond to perceived environmental needs with dispatch, using focused restoration efforts to capitalize on the best available technical information and continually improving the effectiveness of management actions. Prospective approaches to monitoring are particularly suited to these conditions.

The following are key components of any monitoring program.

Goals and Objectives

Monitoring programs should be capable of determining whether current or proposed management practices are maintaining the ecological integrity of the target environmental systems and the ability of the system to deliver expected goods and services (for example, number of salmon or erosion control by vegetation). Certainly no universal set of goals or objectives characterize a "high quality" environmental state or can apply to all ecosystems subject to management and monitoring. But each proposed management action (or ongoing management action for which new monitoring is being proposed) should be accompanied by a set of specific project goals that guide the development of monitoring objectives. Management goals may take many forms – e.g., a target number of brush rabbits, a restored riparian forest with a specific composition and structure, or a floodplain of predetermined extent inundated for an expected time period. Those goals may be articulated in response to a legal mandate, for example, recovery goals under the Endangered Species Act or as attainment of goals under the Clean Water Act. Whatever the basis for a management goal, the goal should be articulated in such a manner that clear, quantifiable objectives can be identified and direct the monitoring design.

Conceptual Models

Barriers to the attainment of management goals and the success of restoration efforts are inevitable. These barriers arise from both human-generated and natural environmental "stressors". Stressors are physical, chemical, or biological phenomena that cause deleterious effects on ecosystems and the constituent elements. Stressors include a wide variety of environmental disturbances, such as wildfire, invasions of exotic species, stream diversions, and conversion to agricultural use. Stressors have defining characteristics, including frequency of occurrence, extent of occurrence, magnitude (intensity and duration), selectivity (elements of the system on which they act), and variability, which allows them to be categorized during development of a monitoring plan. Stressors that act on managed ecosystems must be described in terms of causes and effects. The description is best presented as a conceptual model that links environmental stressors to environmental attributes of concern.

Sound monitoring programs are founded on one or more conceptual models. Well-designed conceptual models enable a monitoring program to investigate relationships between environmental perturbations and likely consequences. Conceptual models outline the connections among ecosystem elements and environmental stressors, the strength and direction of those links, and attributes that can be used to characterize the state of resources. Conceptual models show how environmental systems function and emphasize anticipated responses to natural and human caused stressors.

A conceptual model that describes the managed system is absolutely necessary to design an effective monitoring program. Although a narrative description of an ecosystem of concern can serve as a conceptual model, conceptual models are especially usefully when presented as visual representations of the relationships among factors that contribute to ecosystem function. Conceptual models should explicitly link ecosystem attributes, which include both abiotic and biotic elements and inputs, to system stressors. The expected cause and effect relationships that result in ecosystem changes identified in the conceptual model serves to assist selection of candidate indicator for measurement in the monitoring program.

Indicator Selection

Because ecosystems are complex, monitoring programs cannot possibly measure all of their attributes. The health of ecosystems, their responses to restoration, and their susceptibility to long-term change must therefore be measured with a limited set of indicators (sometimes referred to as performance measures). The theory and practice of indicator selection is demanding; selection of ineffective indicators will cause a monitoring program to fail.

A conceptual model provides a basis for selection of candidate indicators, the responses of which are expected to reflect ecosystem changes that may result from management actions or environmental stressors. Indicators are expected to provide information on other resources and attributes of the same ecological system. The most effective indicators respond in a fashion similar to the dynamics of the ecosystem that supports them and respond rapidly to changes in their environment. Their changes in status can be accurately measured, their natural variability is sufficiently limited that changes in response to management can be differentiated from background variation, and they can be measured in a cost-effective manner.

For purposes of monitoring under the CALFED Bay-Delta program, we recognize at least three categories of indicators. Function or process indicators measure ecosystem processes and their rates. Processes include but are not limited to primary productivity, nutrient cycling, sediment accumulation, and water flows. Indicators of ecosystem structure are used to assess ecosystem structure at any spatial extent and resolution, from local patches of vegetation to patch distributions and connectivity across the landscape. Species-based indicators—an important category of indicators for the CALFED Bay-Delta Program given its focus on at-risk and listed species – typically are members of taxonomic groups that are important to ecosystem function (predators, pollinators, decomposers), provide insight into the integrity of the ecosystem (that is, they may serve as umbrella species, keystone species, or ecological engineers), are direct targets for management (because they are recognized as threatened or endangered), or sensitive to ecosystem changes.

Candidate indicators for monitoring should provide a clear "signal", alerting managers to the true state of the system in time to respond with appropriate action. The most effective indicators are those whose mechanistic behavior in response to a specific stressor is well understood. Because no standing body of information exists that can *a priori* guide and assure selection of the best indicators in all management scenarios, best professional judgment must be used, along with available empirical data and pertinent literature, in evaluating potential indicators in many management scenarios. Subsequent data collection will be the means by which the effectiveness of any given indicator is proven.

Sampling Design

Addressing the full breadth of challenges in designing a sampling plan for monitoring after indicators are selected is beyond the scope of this document. However, several key issues deserve attention. First, it is necessary to estimate the status and trend(s) of an indicator within appropriate bounds of accuracy; this demands substantial statistical expertise. Essential to the monitoring program is establishment of expected values (or trends) of indicators as benchmarks against which the indicator states are compared following management actions. Second, values that will be used to trigger management responses must be identified. This requires information on or assumptions about what constitutes an ecological effect sufficiently great to trigger management response or amendment – the effect size – as well as a sampling scheme that is adequate to detect that effect. Only by identifying appropriate trigger points (a value or distribution of values) for management intervention is a monitoring plan made operational. Third, a substantial number of practical issues of design and analysis pervade the development of a sampling frame – boundaries to the ecosystem and area subject to management must be defined; the temporal resolution and extent of sampling must be established; a sampling size appropriate to estimate the value of the indicator must be identified; a survey design that responds to spatial heterogeneity needs to be constructed; and units of measure for each indicator must be chosen.

Other issues important to the design of a successful monitoring program are discussed in varying detail in many of the sources below.

Additional Resources

Perhaps the single best discussion of environmental monitoring, including the need for rigor in program design and adherence to a logical step-down process in the development stressor-based prospective data collection, is found in

Noon, B. R., 2003. Conceptual issues in monitoring ecological resources. Pp. 27-72 in Monitoring Ecosystems: Interdisciplinary approaches for evaluating ecoregional initiatives. Washington, D. C.: Island Press.

Much of the above discussion was adapted from that source. Other sources of useful information include

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Landres, P. B., J. Verner, and J.W. Thomas. 1988. Ecological use of vertebrate indicator species: A critique. *Conservation Biology* 2:316-318.

Morrison, M. L., and B.G. Marcot. 1995. An evaluation of resource inventory and monitoring program used in national forest planning. *Environmental Management* 19:147-156.

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